High resolution spatial and temporal laboratory seismic datasets by Laser Doppler Vibrometry

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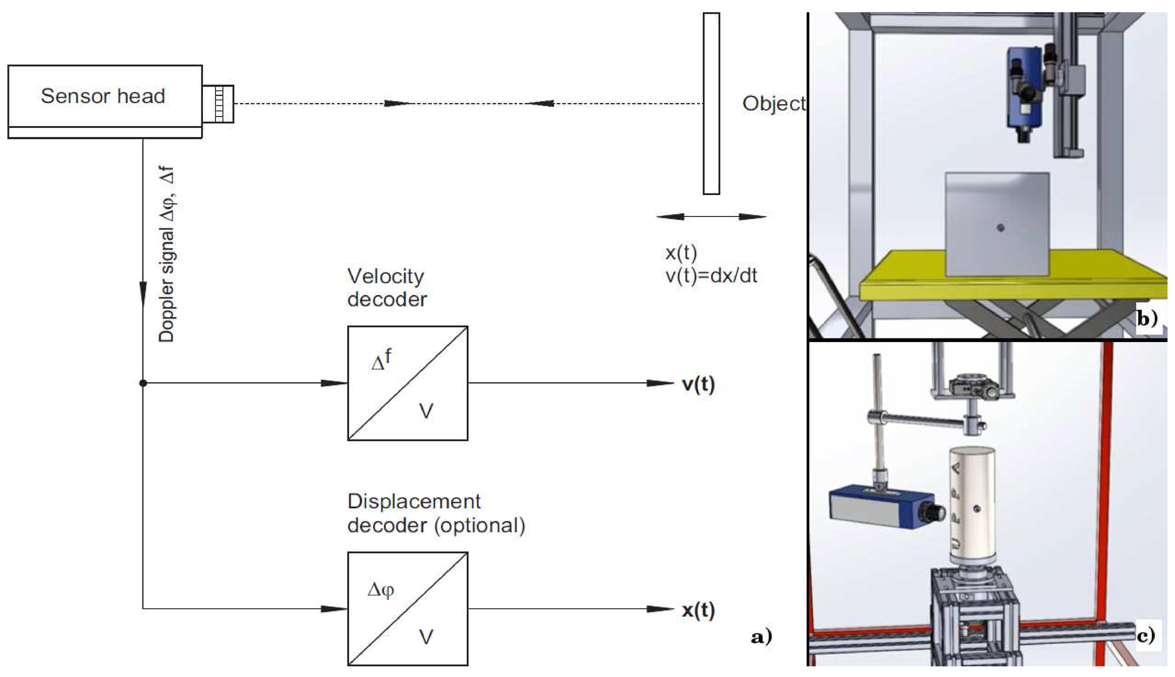
Research context & objectives

We propose to perform sub-metric scale seismic measurements with innovative experimental tools in a laboratory environment which reproduces large-scale field explorations in well conditioned and controlled environment. The purpose is to develop high resolution seismic methods on various natural samples, that can be transferred later to large-scale field conditions. Seismic waves are produced in our experiments by a P-wave piezoelectric transducer stuck to the sample surface. Nanometer mechanical displacements induced by the transducer are measured by LDV around the sample. The data acquisition chain is tested in an aluminum cuboid of 280 mm side length. High-resolution (ds ≈ 1 mm, dt ≈ 10 ns) unidimensional mappings of surface displacements on various faces of the cuboid are performed; Furthermore, multidimensional datasets are obtained on both cuboid and cylinder samples by *full-field 3D Scanning Vibrometers* thanks to the collaboration with *Polytec GmbH*. Parallel 2D/3D numerical simulations using IPDG[1] discretization method are done to match the experimental data.

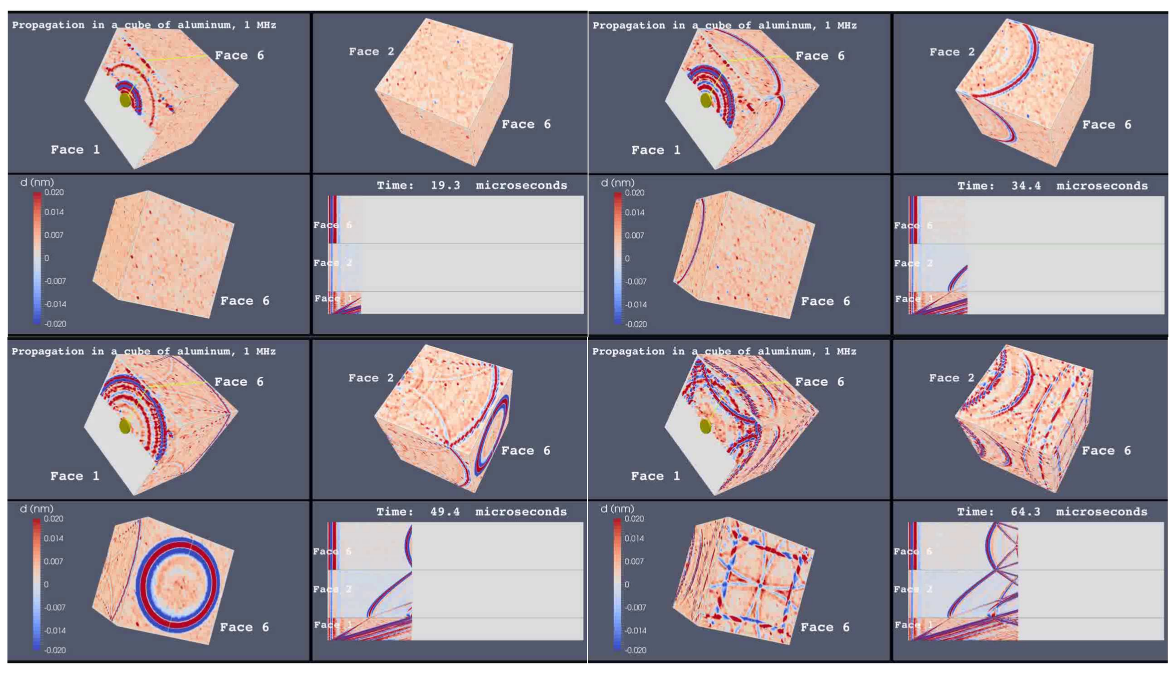
LDV and geophysical applications

Laser Doppler Vibrometer



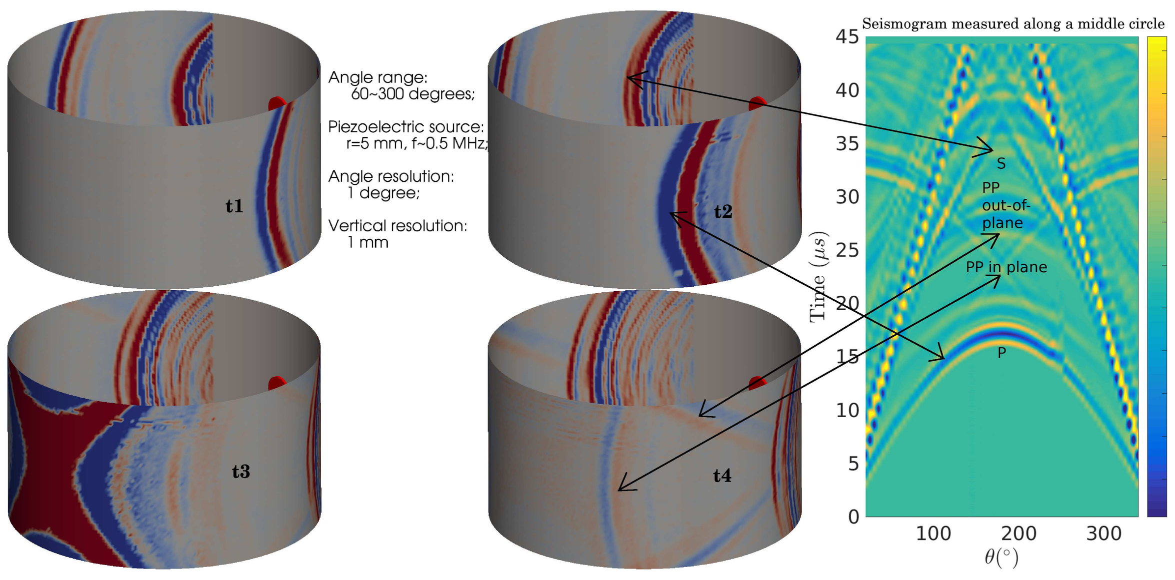
a) : Schematic view of the LDV principle; b) : Experimental setup of measurements on an Alu block by a single point LDV sensor. c) : Experimental setup for the Alu cylinder.

Displacement mapping on an aluminum block



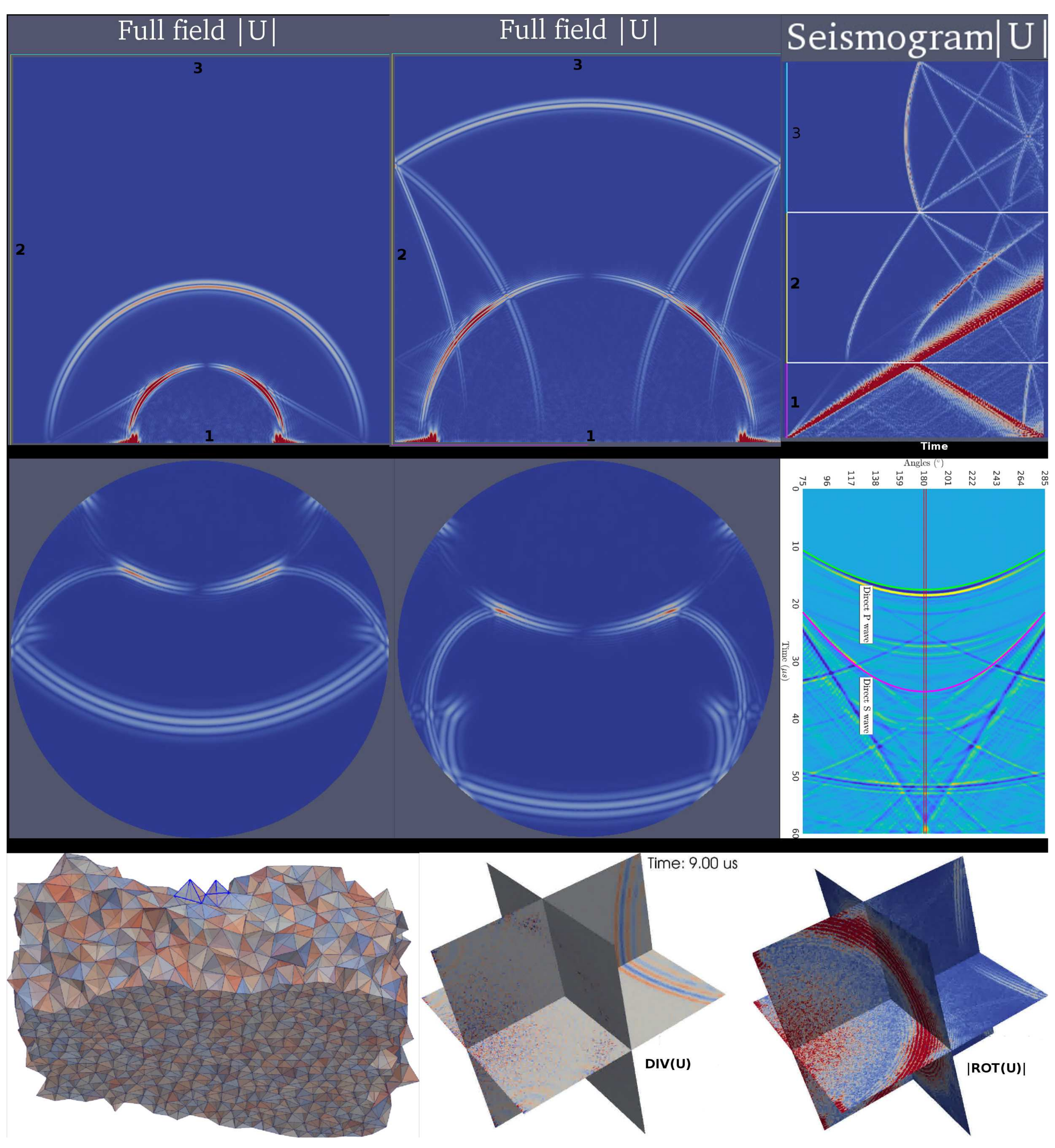
Normal components of displacements are measured on face 1 (source face), face 2 (upper face) and face 6 (opposite face). Snapshots and seismogram (along middle lines) at/until 19.3 μs, 34.4 μs, 49.4 μs and 64.3 μs are displayed.

Displacement mapping on an aluminum core



Radial components of displacements are measured. Snapshots and seismogram (around the mid-section) at/until t1, t2, t3, t4 (t1 < t2 < t3 < t4) are shown.

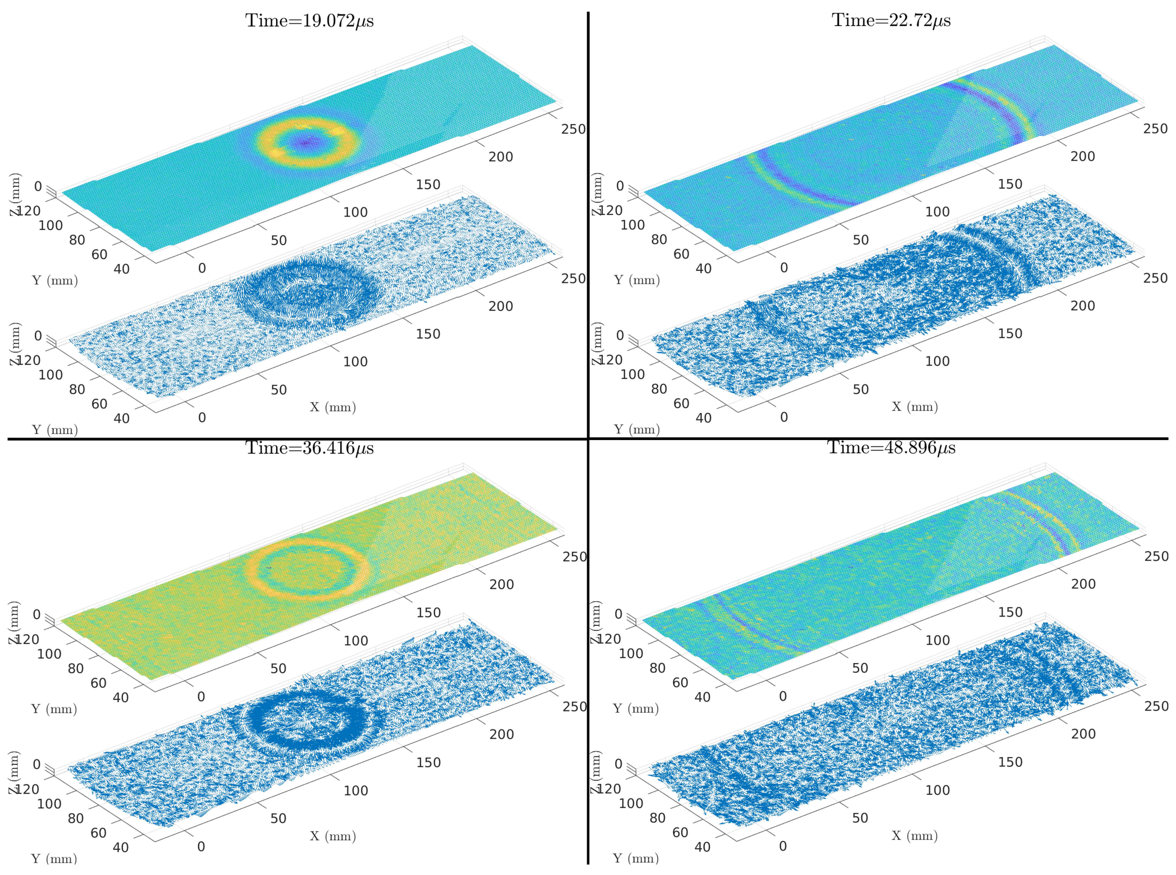
Corresponding simulations



Corresponding 2D and 3D simulations by Finite Element method featured with IPDG[1]. The 3D simulation is performed in a reduced model with Absorbing Boundary Conditions due to memory limits.

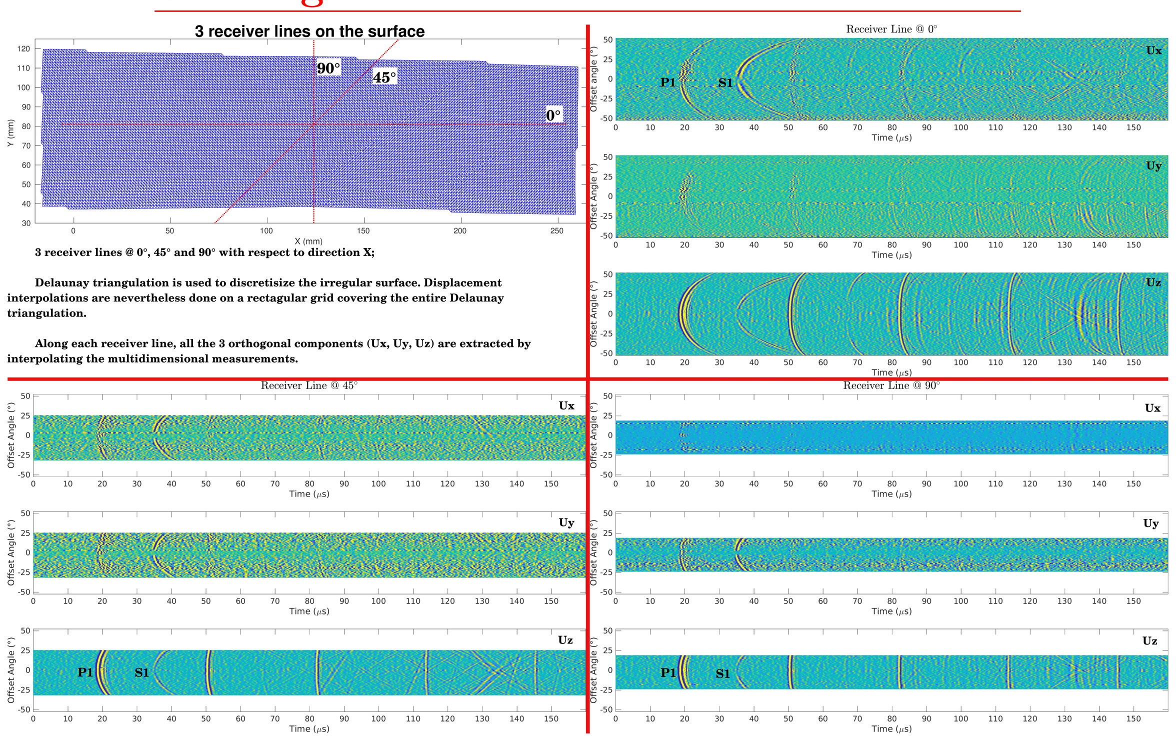
Multidimensional measurements

On a flat surface (280 × 280 × 100 mm^3 Alu block)



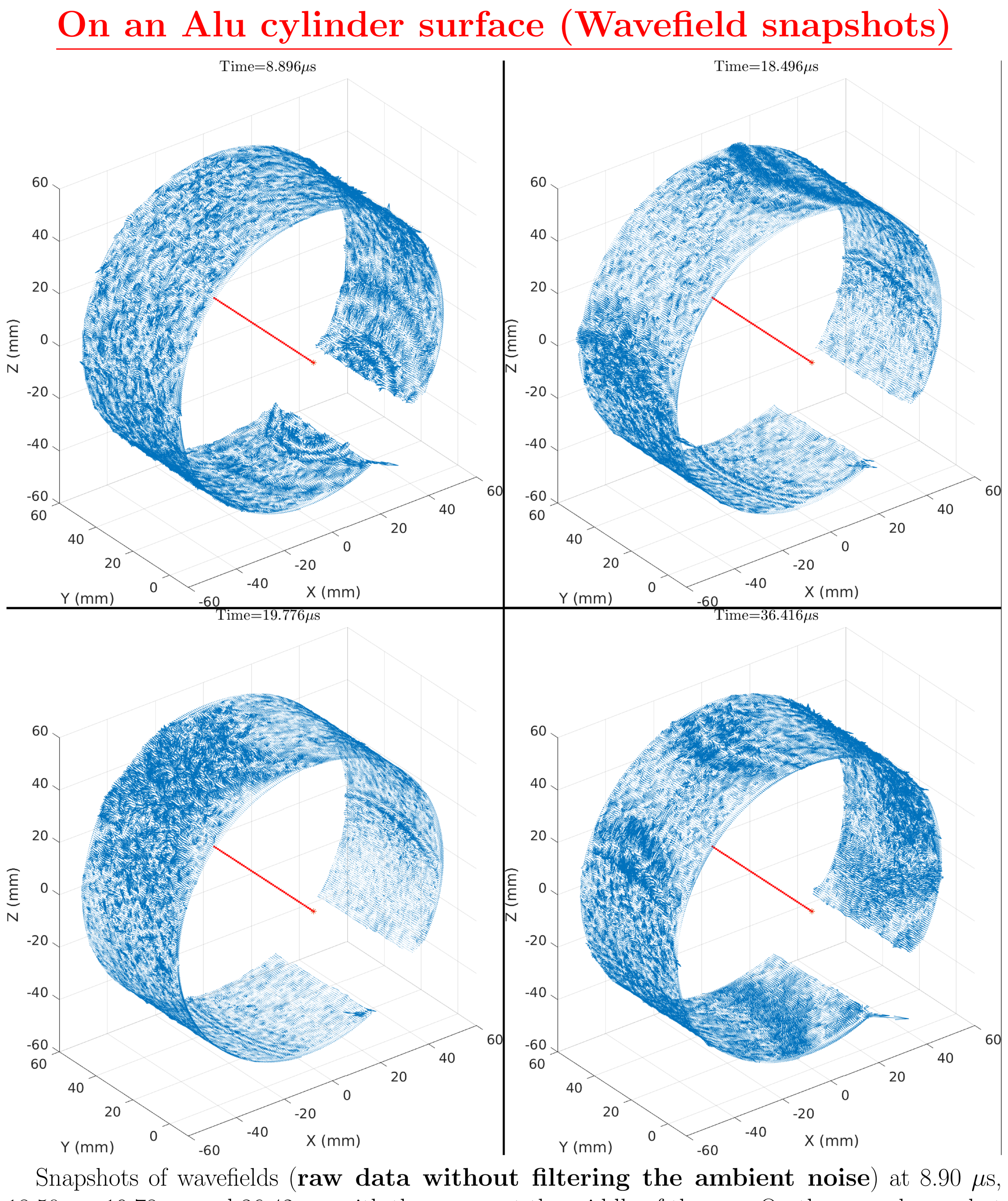
Snapshots of the displacements calculated by integrating the velocity measurements (**raw data without filtering the ambient noise**) at 19.07 μs, 22.72 μs, 36.42 μs and 48.90 μs. The first two are highlighted by P wave fields and the laser two by S waves. We can clearly see the different polarizations respectively for P and S waves.

Seismogram from the flat-surface dataset



Seismogram extracted from **raw data**. The out-of-plane components (U_z) are relatively strong on all the 3 receiver lines because the seismic source points to this direction. The relative energy of the in-plane components (U_x and U_y) depends on the receiver line orientation. Along the receiver line at 0° (X direction), U_x predominates, while at 90° (Y direction), U_y predominates. U_x and U_y are equally distributed along the 45° receiver line. These quantitative observations are coherent with the symmetry of wave propagation in homogeneous media. The full-field 3D scanning vibrometer measures evidently the out-of-plane components as well as the in-plane components.

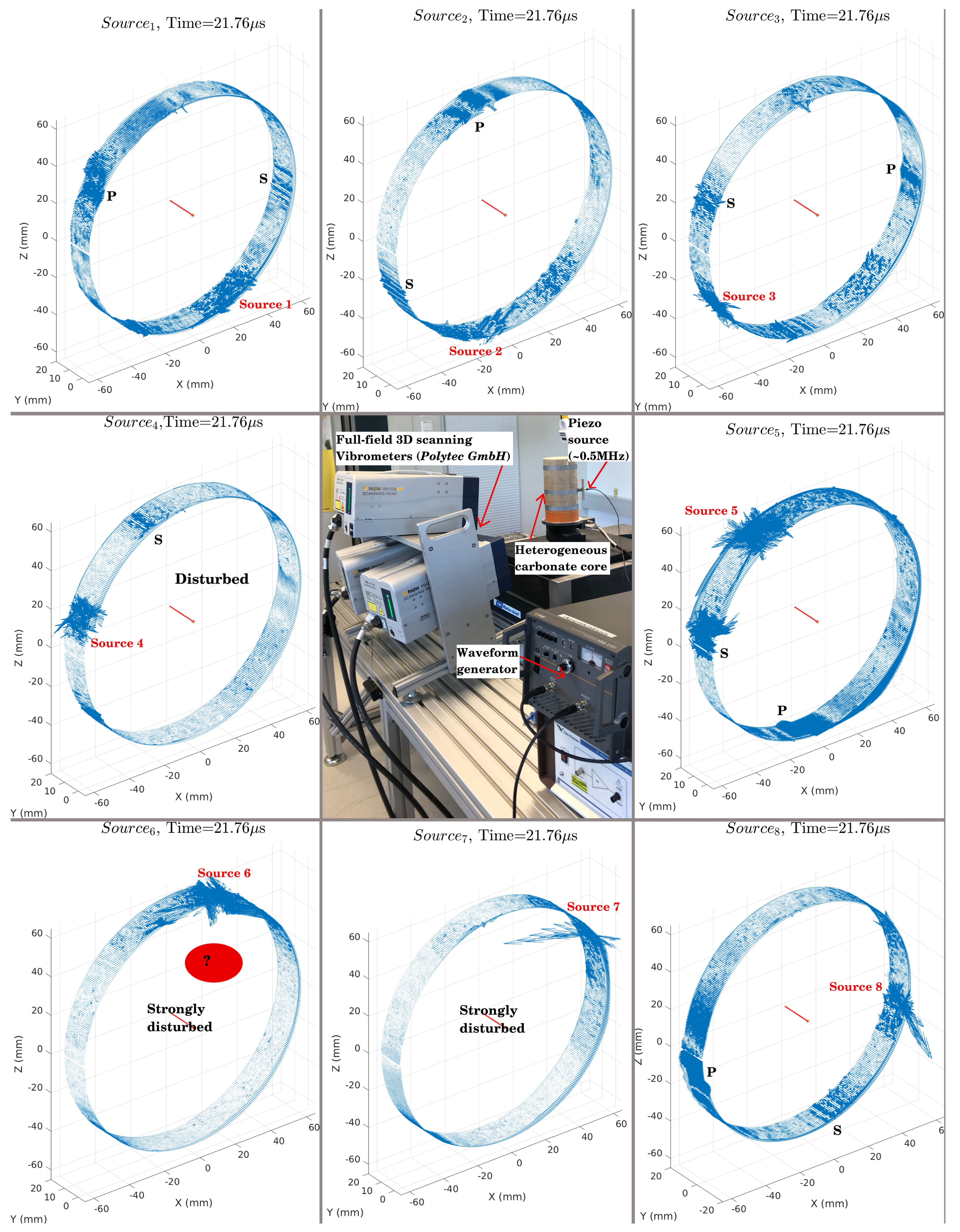
On an Alu cylinder surface (Wavefield snapshots)



Snapshots of wavefields (**raw data without filtering the ambient noise**) at 8.90 μs, 18.50 μs, 19.78 μs and 36.42 μs, with the source at the middle of the gap. On the second snapshot we can clearly see the symmetric P wave fields in the front, followed by slower S waves. The different polarization of S waves are highlighted on the last one.

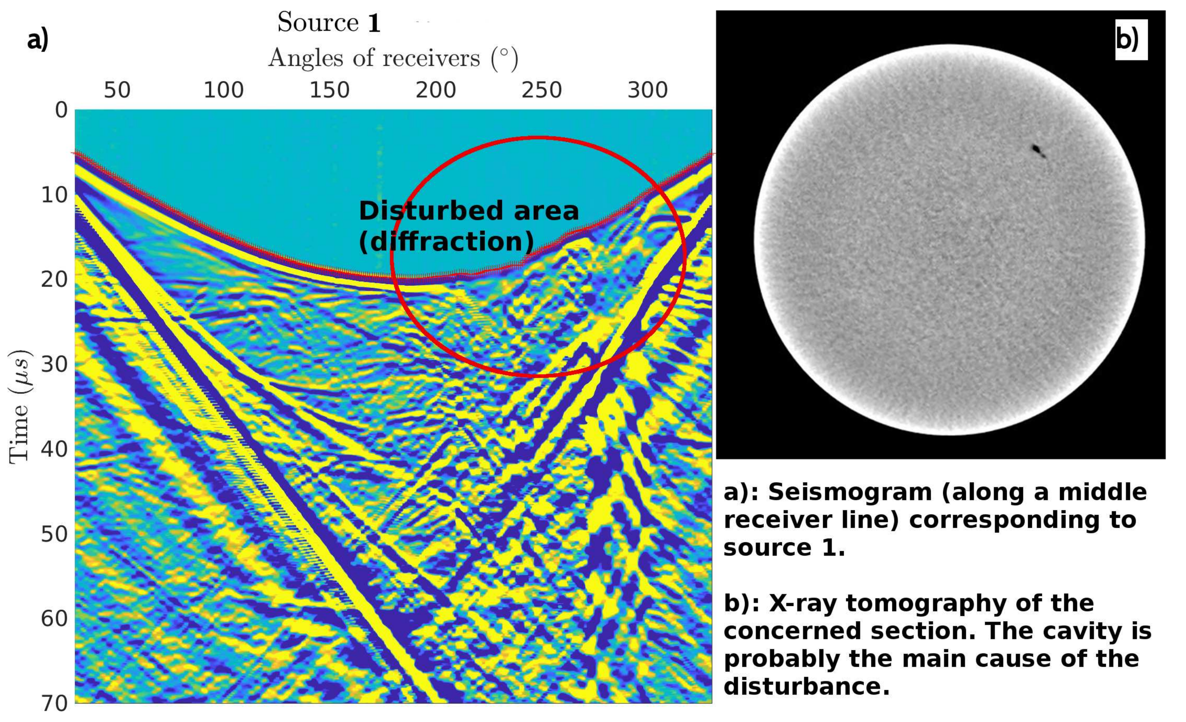
Application on carbonate core

Experimental setup and wavefield snapshots



Snapshots at 21.76 μs for each source position. 8 uniformly distributed sources are deployed around the middle section of the core. Measurements close to the sources are not reliable because of instrumentation obstacles. The wavefield vectors are no longer symmetric in space due to the heterogeneities inside the natural rock. We can still recognize the P wavefield and S wavefield, however, they are strongly disturbed in the cases of source 6 and source 7, indicating probably an obstacle inside the core near these two sources.

Seismogram and X-ray tomography



a): Seismogram (along a middle receiver line) corresponding to source 1.

b): X-ray tomography of the concerned section. The cavity is probably the main cause of the disturbance.

Conclusion :

The excellent agreement between experiments and simulations demonstrates that the full wavefield is nicely recorded by the **single point LDV**, reciprocally validating our numerical scheme and models. A first qualitative analysis on the **multidimensional** data confirmed the data quality and the capability of the full-field 3D scanning vibrometer. We can then perform basic time-lapse tomography in order to get a first insight of the elastic wave velocity models for the carbonate core. Further analyses on simulated and experimental multidimensional data will enable us to look quantitatively into the **polarizations** and quantify the Amplitude *vs* Angle (**AVA**[2]) influence on the surface measurements. Seismic attributes such as amplitudes and frequencies contain also rich information on other **rock physics properties** including quality factor, anisotropy and proelasticity etc.[3]. The full-field data can eventually be used to test **Full Waveform Inversion** schemes which would in turn yield more reliable and accurate inversion results.

References

[1] Caroline Baldassari. *Modélisation et simulation numérique pour la migration terrestre par équation d'ondes.* PhD thesis, Université de Pau et des Pays de l'Adour, 2009.

[2] John P Castagna and Milo M Backus. *Offset-dependent reflectivity - Theory and practice of AVO analysis.* Society of Exploration Geophysicists, 1993.

[3] Bastien Dupuy, Stéphane Garambois, Amir Asnaashari, Hadi M Balhareth, Martin Landrø, Alexey Stovas, and Jean Virieux. Estimation of rock physics properties from seismic attributes ?part 2 : Applications. *Geophysics*, 81(4) :M55–M69, 2016.